High Spatial Resolution MEMS Surface Pressure Sensor Array for Transonic Compressor IGV Measurement

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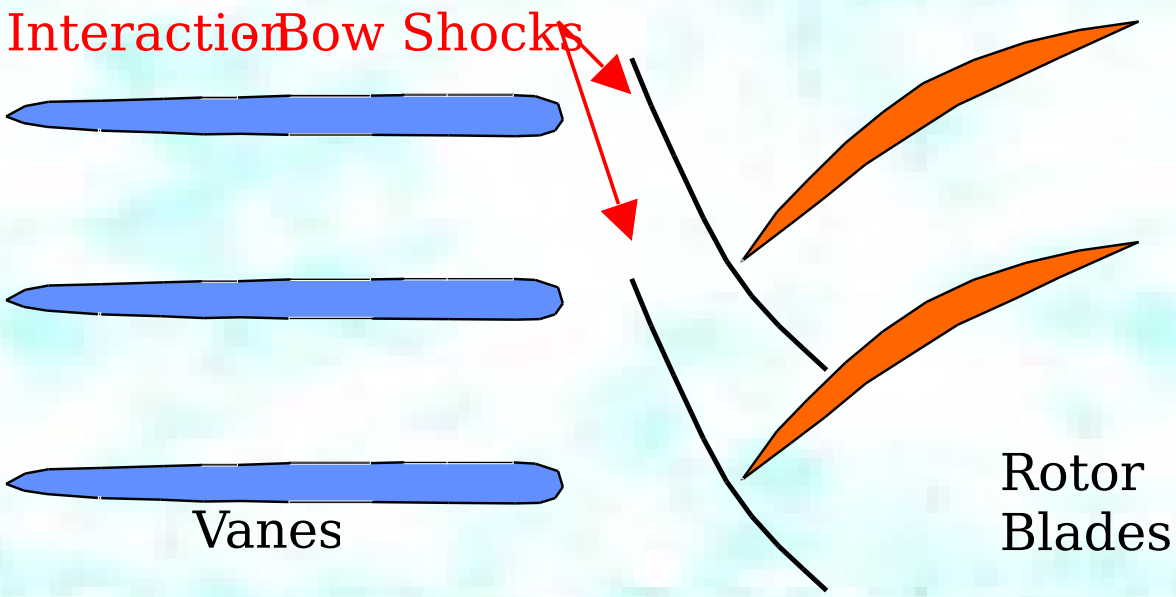
Outline

- Introduction
- IGV Instrumentation
  - Research Facility
  - Previous Instrumentation
  - Flex Circuit Substrate
  - Pressure Transducer Dies
  - Multiplexer Array
  - Trimmer Circuits & Static Calibration
- Preliminary Measurements
- Conclusions

Introduction & Motivation

- Forced response is an important component of HCF analysis
  - Vane/blade interaction a principal cause of unsteady aerodynamics
  - Detailed measurements required to determine flow physics
- Shock interaction is a main driver in unsteady aerodynamics
  - Insight into bow shock flow physics is needed
  - Shock/boundary layer interaction in end-wall region is unknown
- MEMS technology is utilized to understand flow physics
  - Increased economical measurement resolution required
  - Decreased installation expense due to MEMS flex circuit technology

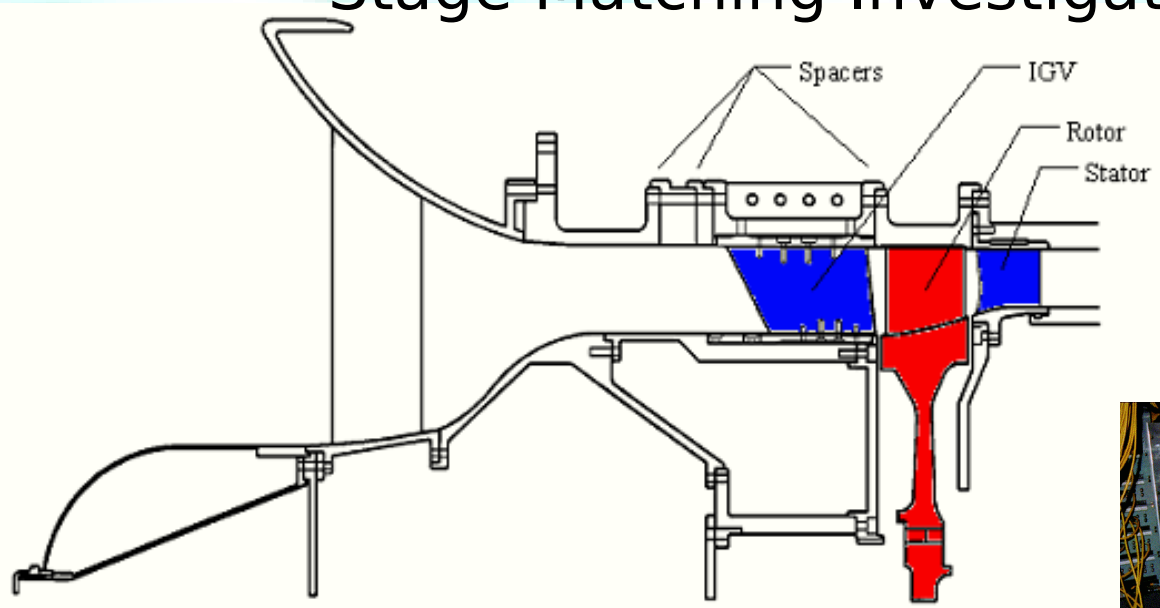
Introduction



- Bow shocks are the primary unsteady driver
- High spatial & frequency resolution data is required to understand the complicated flow physics involved

Research Facility

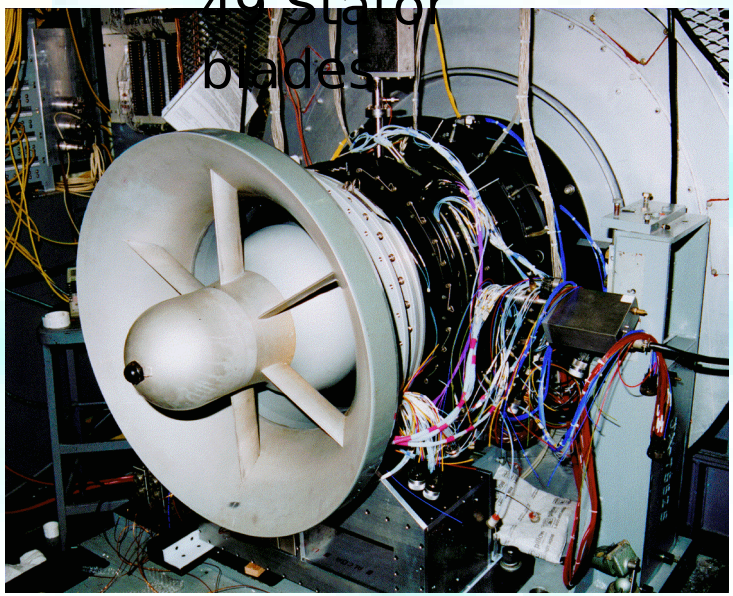
Compressor Aero Research Laboratory (CARL) Stage Matching Investigation (SMI) Rig



12, 24, 40 IGV's

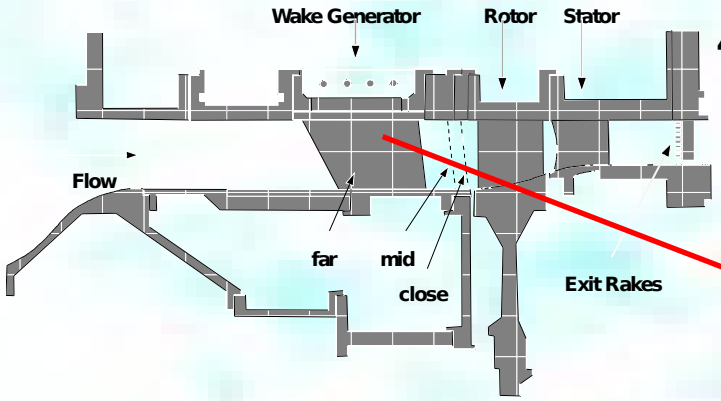
33 Rotor blades

49 Stator blades

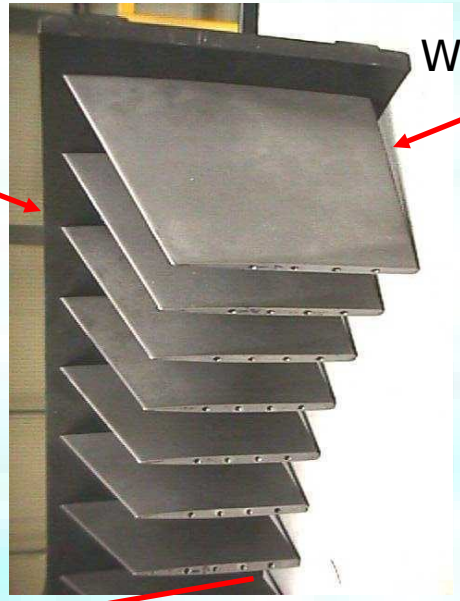


3 possible IGV/Rotor spacings:
12, 26, 56% IGV Chord
(0.36", 0.75", 1.68")

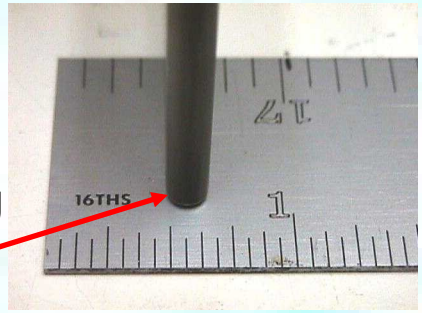
Inlet Guide Vane (IGV)



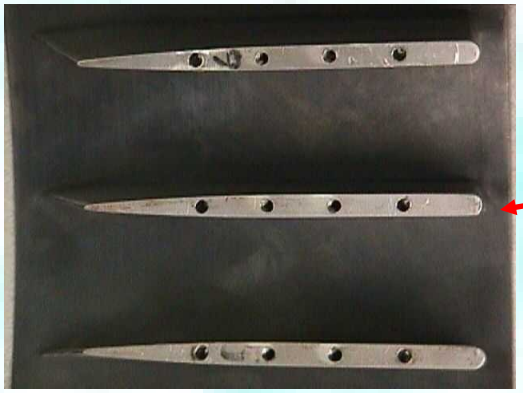
40-Strut Configuration



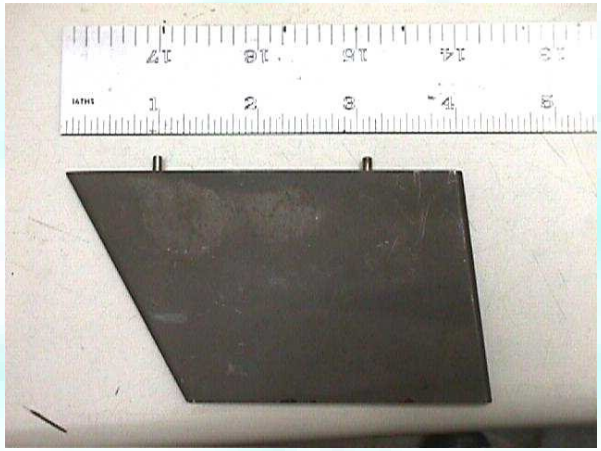
WG Trailing Edge



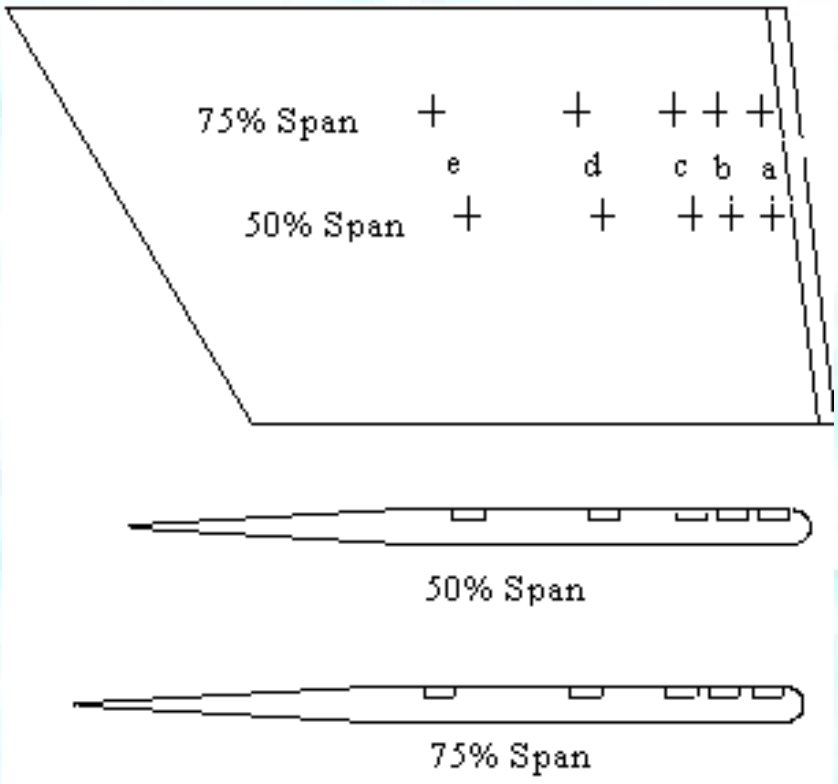
Trailing Edge Thickness at Mid Chord 0.06

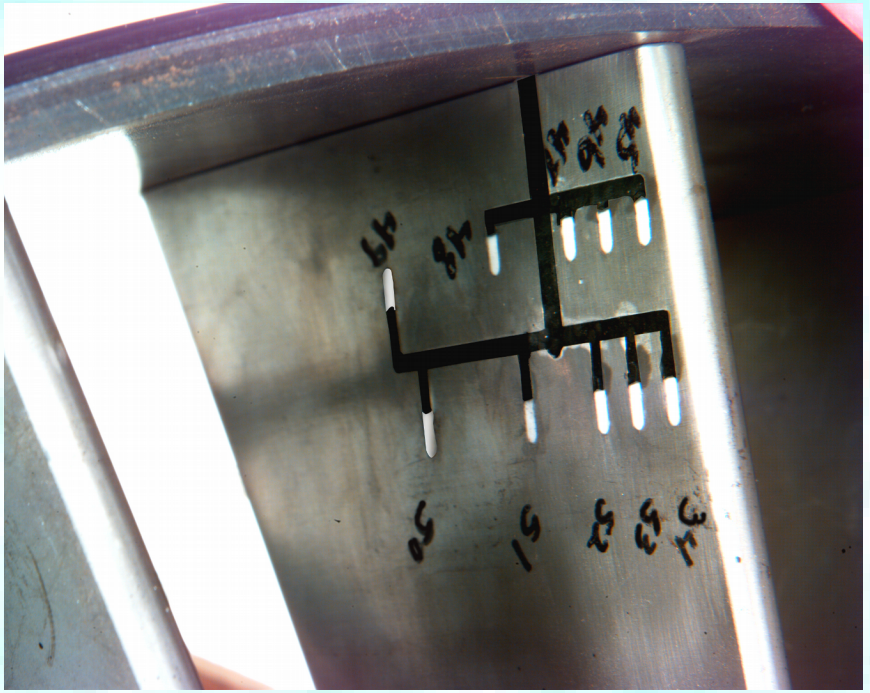


Airfoil Cross Section Hub



Previous Instrumentation

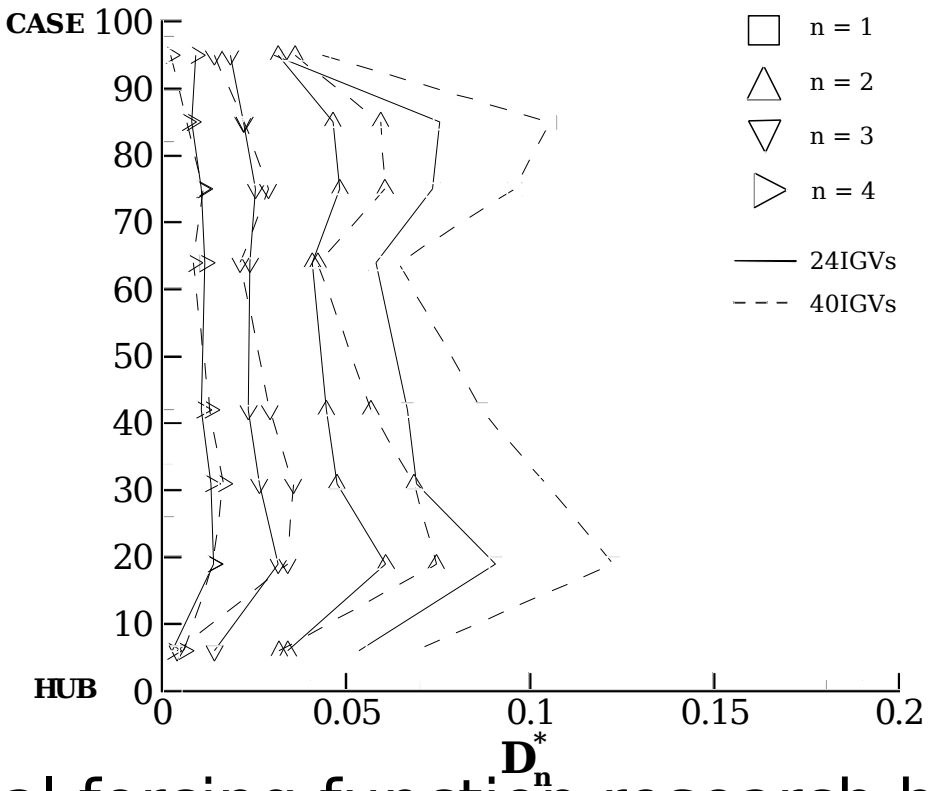




- 10 Kulite LQ-125 pressure transducers
- 25 psia
- 95%, 89%, 83%, 70%, 50% chordwise locations
- $25,000

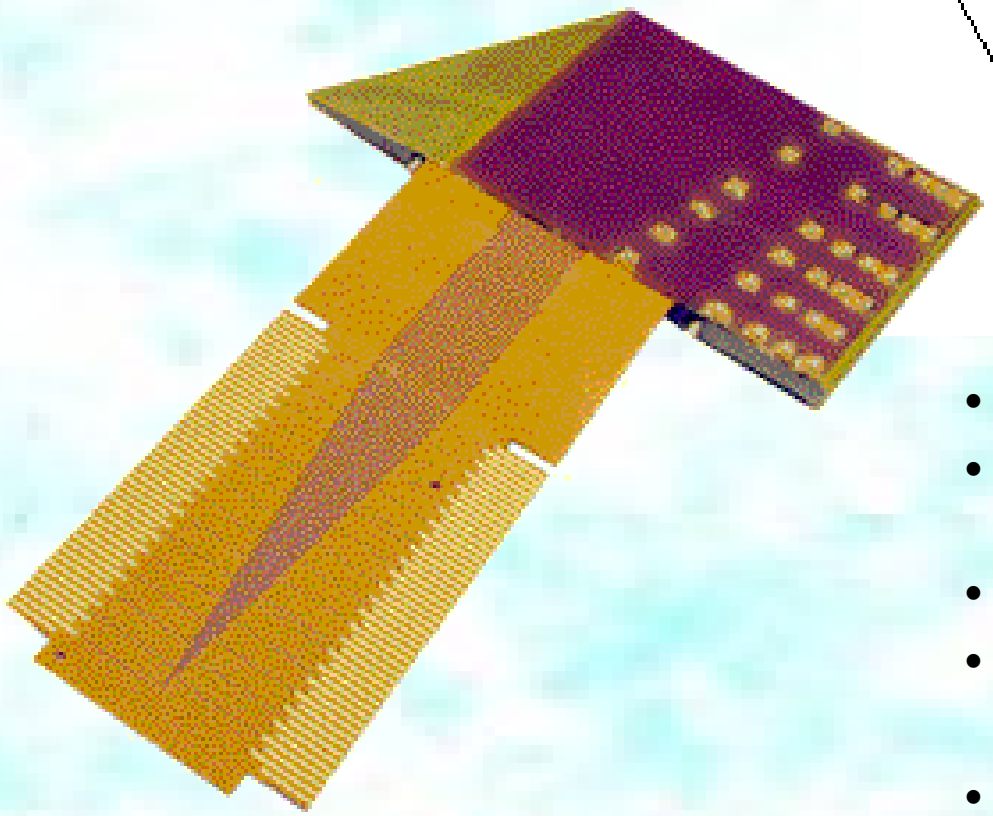
Probasco et al. 1997

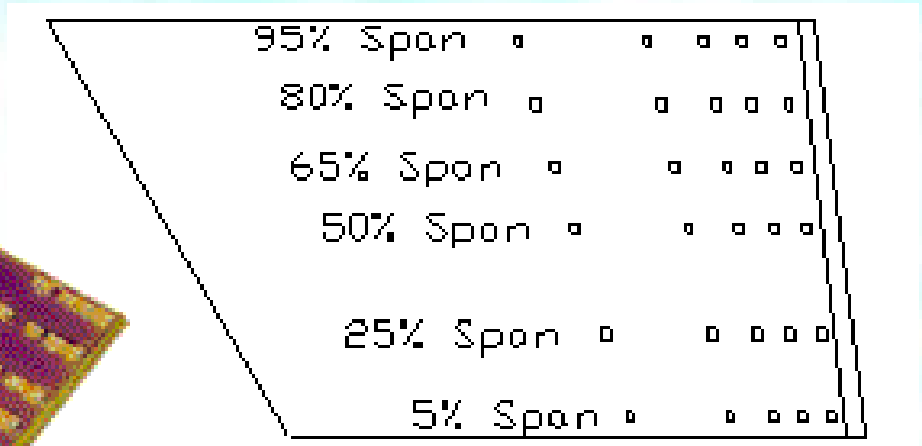
3-D Flow Field



- Vortical forcing function research by Koch et al. 2000 demonstrates the 3-D nature of flow in the SMI rig

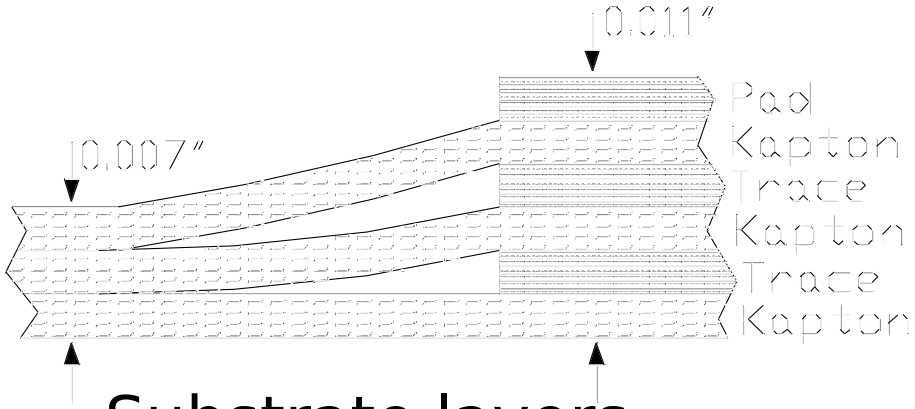
MEMS Sensor Array



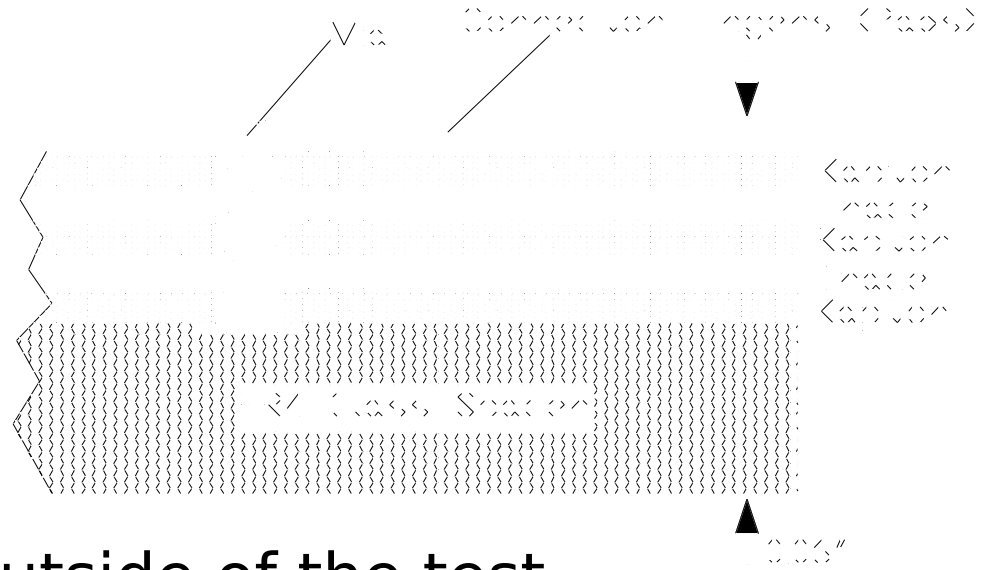


- 30 Sensors - 15 psia
- 3-layer flex circuit substrate ~ 0.01” thick
- ~ 0.03” total thickness
- 95%, 90%, 85%,77%, 60% chordwise locations
- $40,000

Flex Circuit Substrate

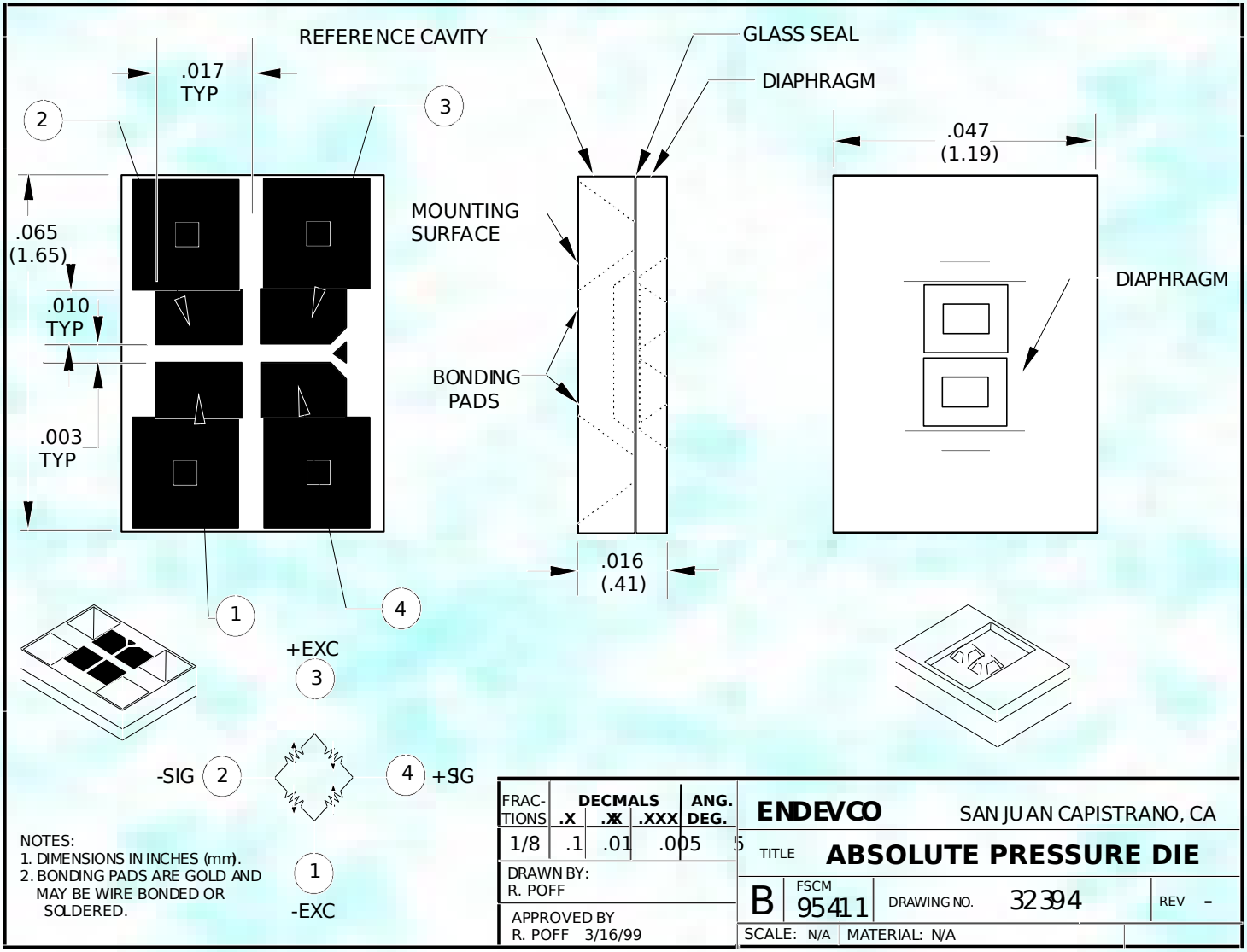


Substrate layers



Outside of the test section

Pressure Transducer Dies



NOTES:
1. DIMENSIONS IN INCHES (mm).
2. BONDING PADS ARE GOLD AND MAY BE WIRE BONDED OR SOLDERED.

FRACTIONS	DECMALS .X	.XX	.XXX	ANG. DEG.
1/8	.1	.01	.005	5

DRAWN BY: R. POFF

APPROVED BY R. POFF 3/16/99

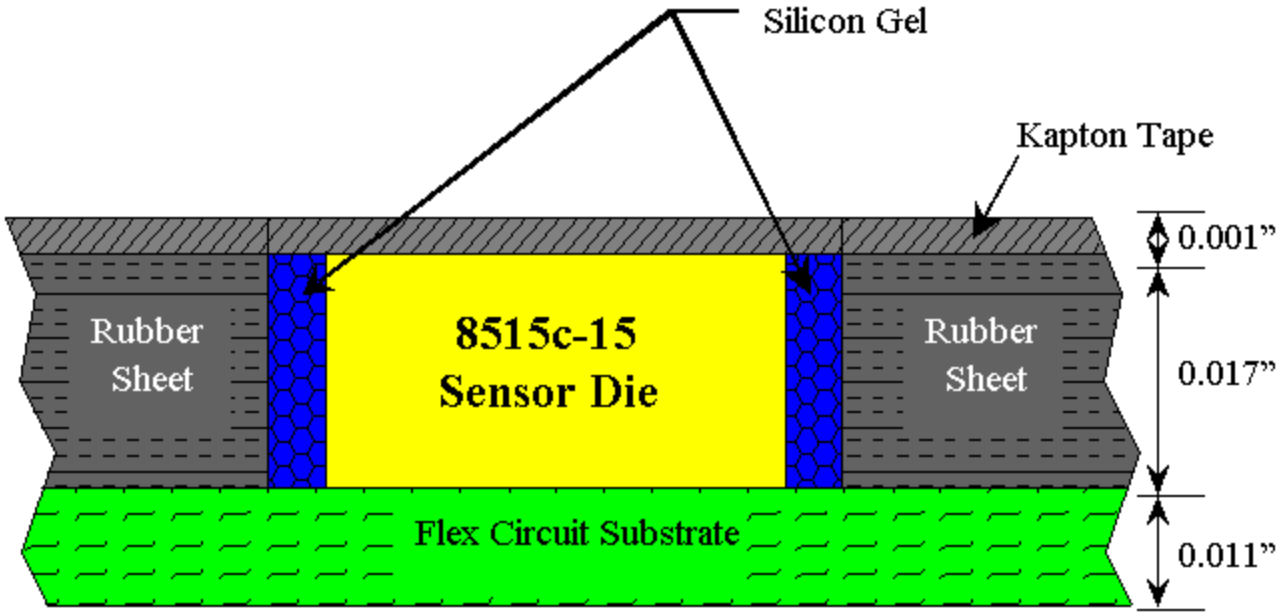
ENDEVCO SAN JUAN CAPISTRANO, CA

TITLE **ABSOLUTE PRESSURE DIE**

B	FSCM 95411	DRAWING NO. 32394	REV -

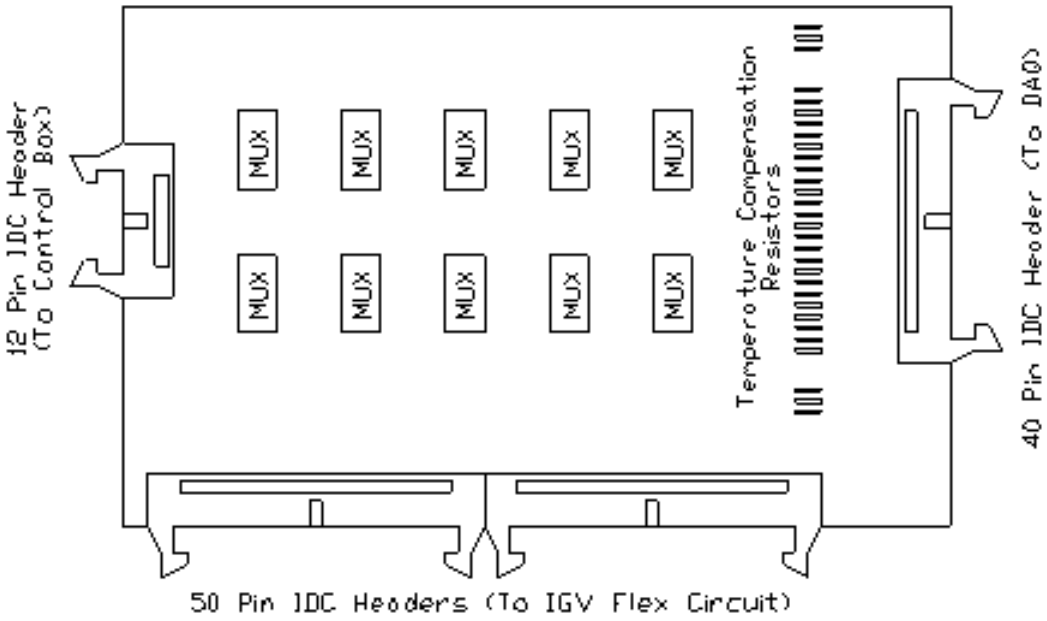
SCALE: N/A MATERIAL: N/A

Sensor Application

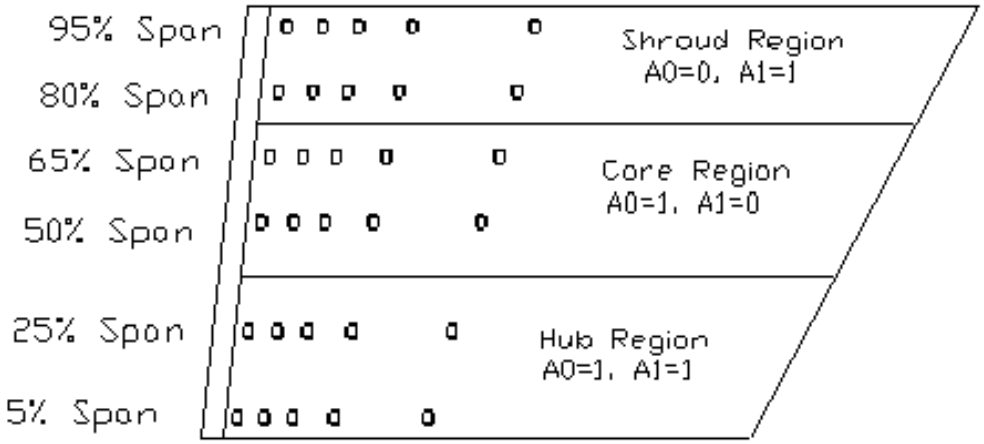


- 30 mil slot machined in IGV
- Rubber sheet fills between sensor dies
- Silicon gel & kapton tape used to contour surface

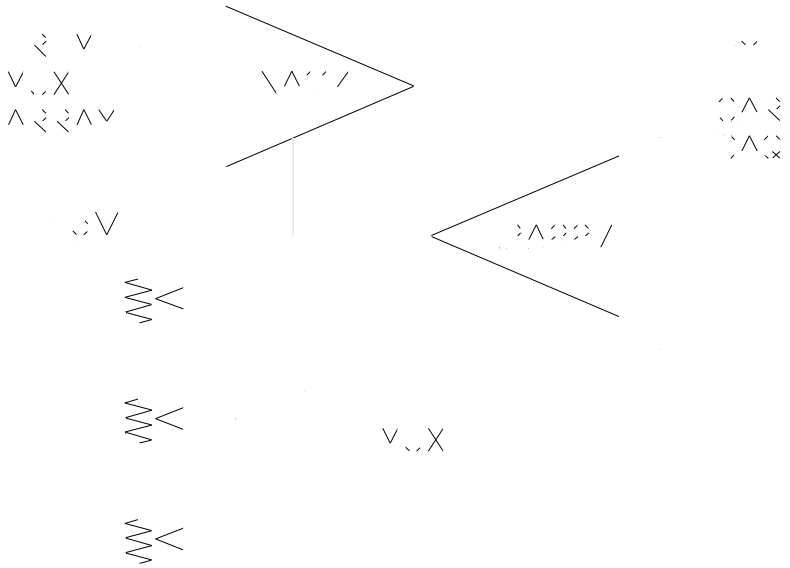
Multiplexed Array

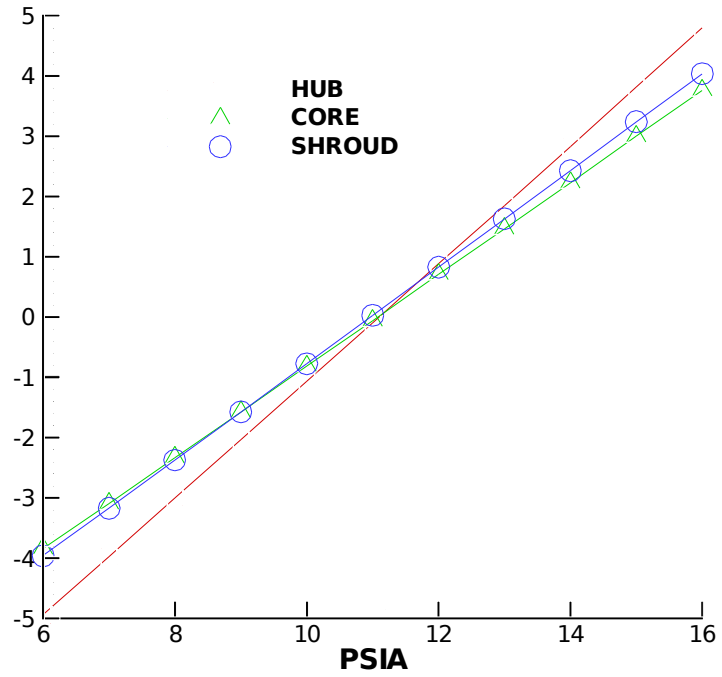


- 2-Board design (stackable)
- 10 MUX/board
- Incorporates thermal compensation resistors
- Remotely controllable



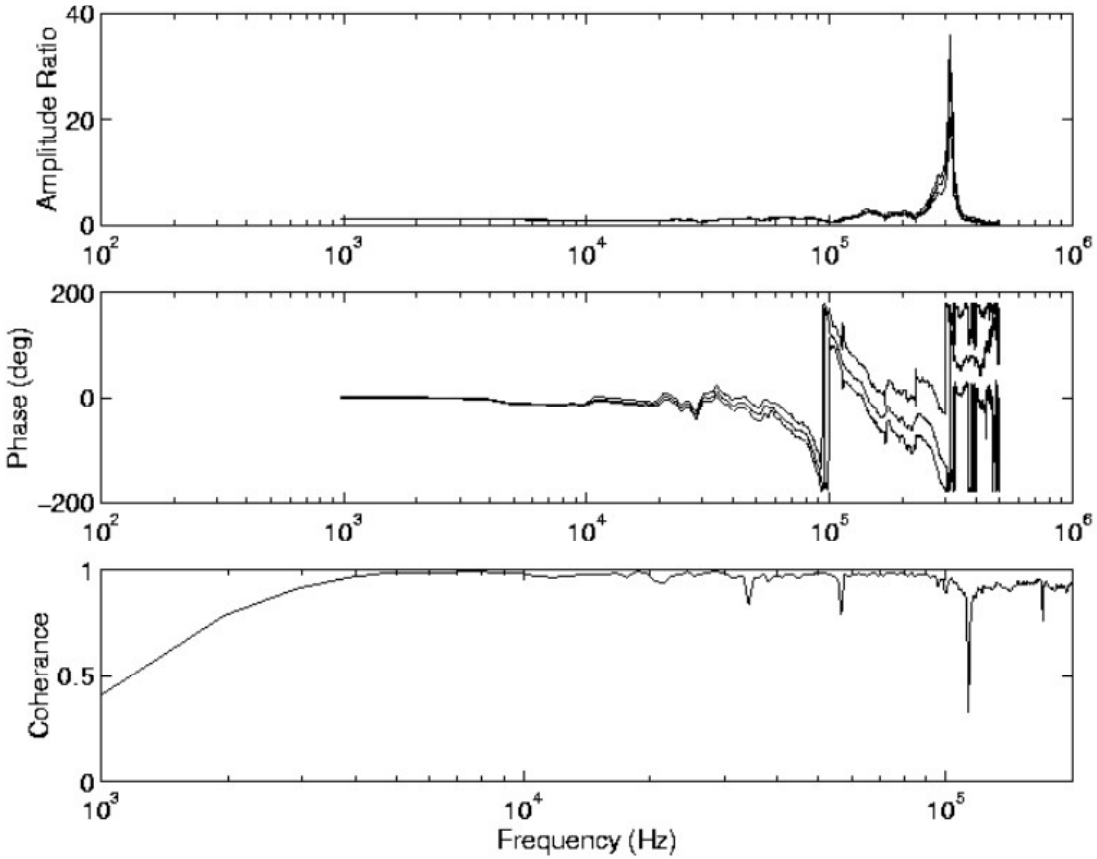
Trimmer Circuit &





- Incorporation of the trimmer circuits allowed for a full DC signal to be obtained with the existing CARL DAQ system
- Static calibration showed excellent linearity of the MEMS pressure sensor array system

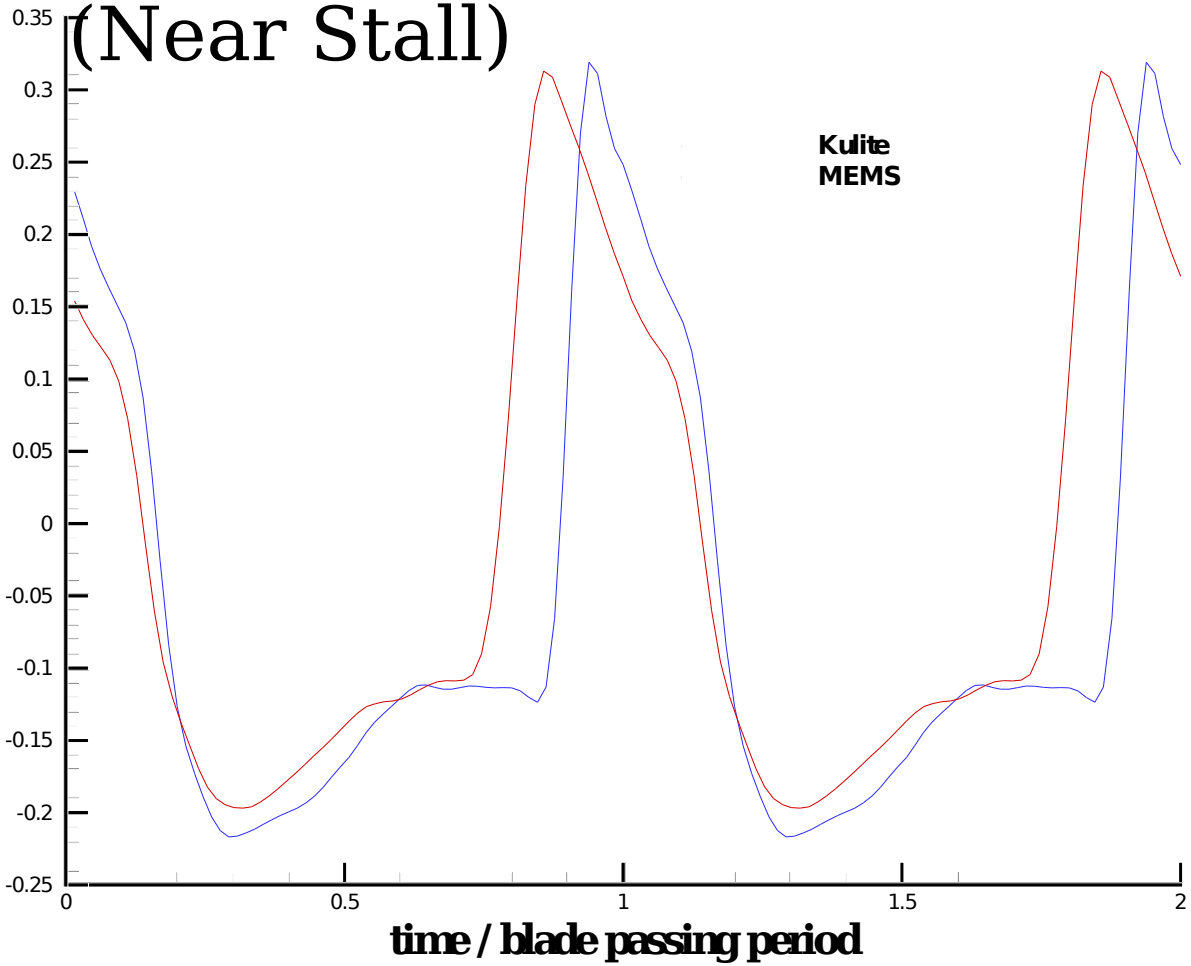
Dynamic Calibration



- WSU Shock Tube Testing
- Usable Frequency BW 30 kHz

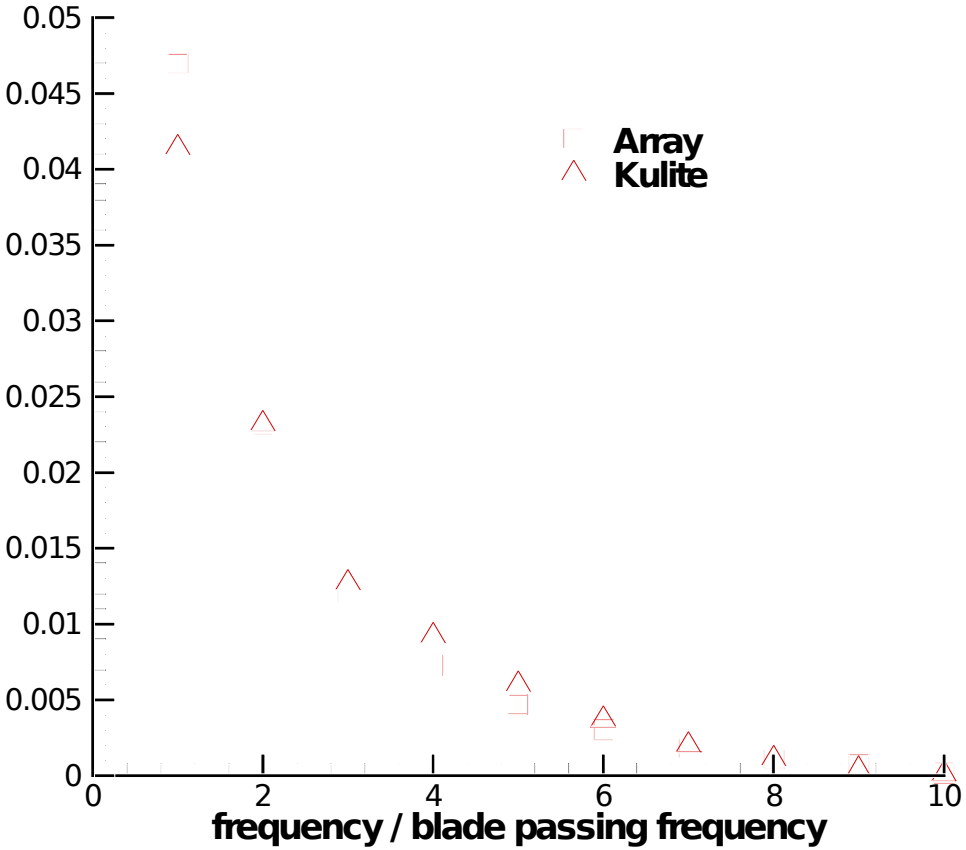
Comparison with Kulite

50% Span, 95% Chord, 105% Speed (Near Stall)



- Favorable agreement with previous sensor data
- Slight phase shift caused by annular shift in physical sensor location

Preliminary Measurements



- 50% Span, 90% Chord, 105% Speed
- 8% variation in 1st harmonic amplitude
- Differences caused by uncertainty in matching test conditions with different ambient conditions

Summary & Conclusions

- MEMS Sensors Designed and Installed
  - 2 IGV blades instrumented - 60 total sensors
  - High spatial and temporal resolution
  - AC and DC pressure components obtained
- High-speed transonic compressor unsteady aerodynamics data
  - Excellent agreement with previous traditional sensors
  - Tip region flow physics including shock/boundary layer interaction measured
  - Spacing and throttle position influences were measured